Nuclear Theory - Course 227

EFFECT OF PHOTONEUTRONS ON REACTOR POWER CHANGES

We have seen how delayed neutrons make reactor regulation possible and how they also slow down power decreases. Now prompt and delayed neutrons are produced directly or indirectly as a result of fission. Other neutrons are also produced in a reactor using heavy water. These are the photoneutrons produced when gamma rays are absorbed in deuterium nuclei.

Photoneutrons are peculiar to reactors using heavy water as a moderator or as a heat transport fluid. They are produced when gamma rays interact with the deuterium nuclei according to the equation: -

$$_1H^2 + \gamma = {}_1H^1 + {}_0n^1$$

Where do the gamma rays come from and when are these photoneutrons produced?

Gamma rays are emitted by radioactive nuclei in the heat transport system, the moderator system and the fuel. So photoneutrons are being produced while the reactor is operating and while these radioactive nuclei are being produced. However, they form a very insignificant part of the total neutron population during reactor operation and cannot really be said to contribute to reactor power.

What of the photoneutrons when the reactor is shut down?

The radioactive nuclei in the moderator and heat transport system decay fairly rapidly and would not exist for long as gamma ray sources. However, some of the fission products, formed in the fuel, have very long half-lives and would remain, as sources of gamma rays, for a long time after the reactor is shut down. Therefore, if heavy water is still present in the reactor core after shutdown, photoneutrons will be produced even though prompt and delayed neutrons are not being produced.

In the Canadian power reactor systems, the heat transport fluid and moderator are both heavy water. The heat transport fluid remains in the reactor during shutdown, but the moderator is usually drained from the reactor. Therefore, during reactor shutdown, a very small photoneutron population exists all the time. When moderator is introduced into the core, prior to starting up the reactor, the photoneutron population immediately increases to a value which depends on the duration of the shut down. Thus a neutron source exists even before the reactor goes critical unless, of course, the reactor has been shutdown for longer than about four months.

Of what significance is this photoneutron source and how does it contribute to power changes? There are two aspects that are important: -

(1) Effect on power reduction

It was indicated, in the previous lesson, that, when negative reactivity was introduced into the reactor, ie, δk is given a negative value, the rate of decrease of power is very quickly determined by the delayed neutrons and finally by the delayed neutron group with the 55.6 second half-life. However, here we now have another group of neutrons which decrease more slowly than the delayed neutrons. These photoneutrons, in fact, decrease at the same rate as the fission products decay.

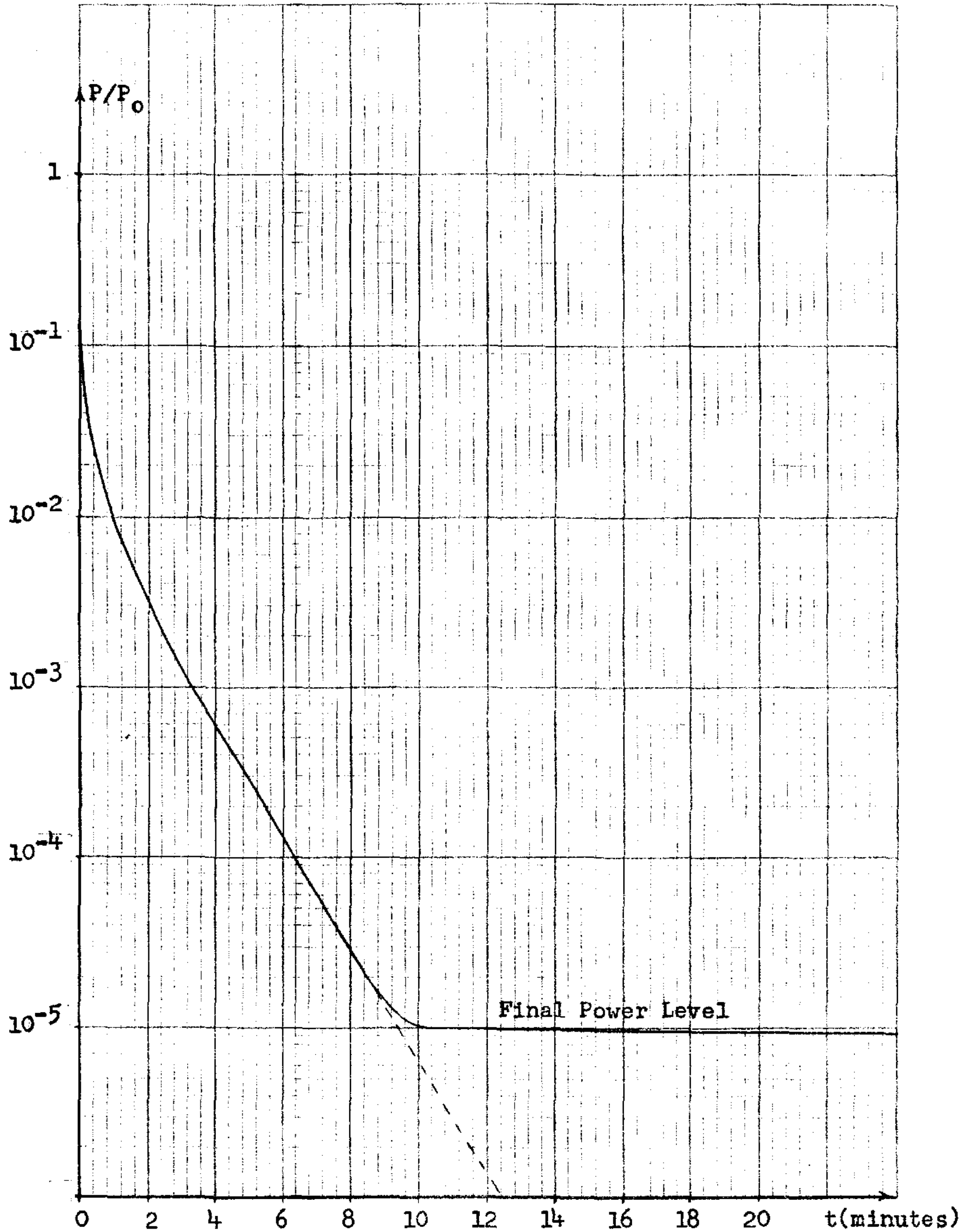
Therefore, the neutron power will decrease, as indicated in Fig. 4 of the previous lesson, until the delayed neutrons have gone and the power will then level out at a value determined by the photoneutron density.

Suppose, for instance that the photoneutron source strength is 30 watts and $\delta k = -30$ mk. Then the final neutron power level would be around 10^{-5} of full power ie, the final value of P/Po is 10^{-5}. The power would therefore decrease as shown in Fig. 1, with the final power level decreasing very slowly as the fission products decay.

The dotted line shows how the power would have continued to decrease without the photoneutrons.

It must be remembered that the graph refers to neutron power as indicated by the neutron measuring instruments. The thermal power does not decrease in this manner because heat is produced by fission product decay. Therefore, the photoneutrons do not affect the thermal power decrease. However, they do not affect the neutron power indications which are obtained on the instruments. The range of neutron power which has to be measured is from 100% down to about 10^{-6} full power, a range of 6 decades. Logarithmic instruments are available which will cover this range. Without photoneutrons, the neutron power range would be far wider than any linear instrument could cover, and highly sensitive instruments would be required when starting up each time. These would have to be removed once higher powers are reached to prevent shortening their useful lives.

(2) Effect on reactor is started up for the first time the only sources of neutrons available are the spontaneous fissions, occuring very infrequently. The first time a reactor is started up a source of neutrons must be placed in the core until the multiplication of neutrons is high enough to give a reading on the instruments. Even so, especially sensitive neutron detectors must be used inside the reactor and these must be removed when the power is high enough to give a reading on the regular instruments. During the first start-up, the reactor must be on manual control, ie, regulated by hand instead of automatically by instruments. If photoneutrons were not present, each start-up would involve the same tedious process as the first one. However, if there is a photoneutron source in the reactor, special detectors and neutron sources are not required. Also the power level soon reaches the point where the reactor can be placed on automatic control.



P/P$_o$
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Final Power Level
0
2
4
6
8
10
12
14
16
18
20
t(minutes)

Fig. 1

ASSIGNMENT

1. (a) How are photoneutrons produced in a reactor?

   (b) Why are they not produced in a reactor in which graphite or light water is used as a moderator?

   (c) Why are the photoneutrons still produced when the reactor is shut down and the prompt and delayed neutrons are no longer produced?

2. How does this photoneutron production affect: -

   (a) the power produced in a reactor?

   (b) the way in which the thermal power decreases after shutdown?

   (c) the way in which the neutron power decreases after shutdown?

3. How is the effect in 2(c) above advantageous as far as the neutron instrumentation is concerned?

4. (a) What are the advantages, during reactor start-up, which result from photoneutron production?

   (b) Why do these advantages not exist when the reactor is started up for the first time?

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